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A CASE ILLUSTRATING THE VALUE OF SATELLITE PICTURES IN FORECASTING FOR THE BRITISH ISLES

By R. A. S. RATCLIFFE, M.A.

Introduction.—TIROS satellites have been taking pictures of the cloud structure for a number of years and nephanalyses* based on these pictures are being regularly disseminated on the transatlantic facsimile network from America. These nephanalyses are received in Bracknell and redistributed over the British facsimile network whenever the senior forecaster considers they are likely to be of value to outstations.

More recently ESSA satellites have been launched and photographs from this series of satellites can be received directly by any suitable receiving station. The ESSA satellite pictures are now being received regularly at Bracknell, up to a maximum of about 10 pictures per day.

The importance of ESSA lies in the fact that the forecaster can now see pictures within about an hour of the photographs being taken instead of being compelled to wait for a much longer time (up to 10 hours) in the case of TIROS.

TIROS photographs are not available at the time they are taken. They can be received only when the satellite comes within range of one of the three American tracking stations and the total delay before the photographs are available is due to the need to wait for this to happen, coupled with the time necessary to convert the photograph to a nephanalysis and for subsequent transmission on the intercontinental facsimile network. The value of these pictures is often doubted ; many people are under the impression that even when available the pictures add little to the forecaster's knowledge of the synoptic situation, at least in our latitudes. To counter this belief a case in which a satellite photograph helped in the preparation of a successful forecast for the British Isles 12–24 hours ahead is illustrated.

The synoptic situation on 8 April 1966.—The synoptic situation as originally analysed by the Central Forecasting Office (CFO) on the afternoon

*JAMES, D. G. and POTHECARY, I. J. W. ; Some aspects of satellite meteorology. *Met. Mag., London*, **94**, 1965, p. 193.

of 8 April is shown in Figure I. This shows the 1500 GMT chart for that date with a frontal system approaching south-west England and a cold front (CB) lying across the Bay of Biscay and close to the Portuguese coast. There were

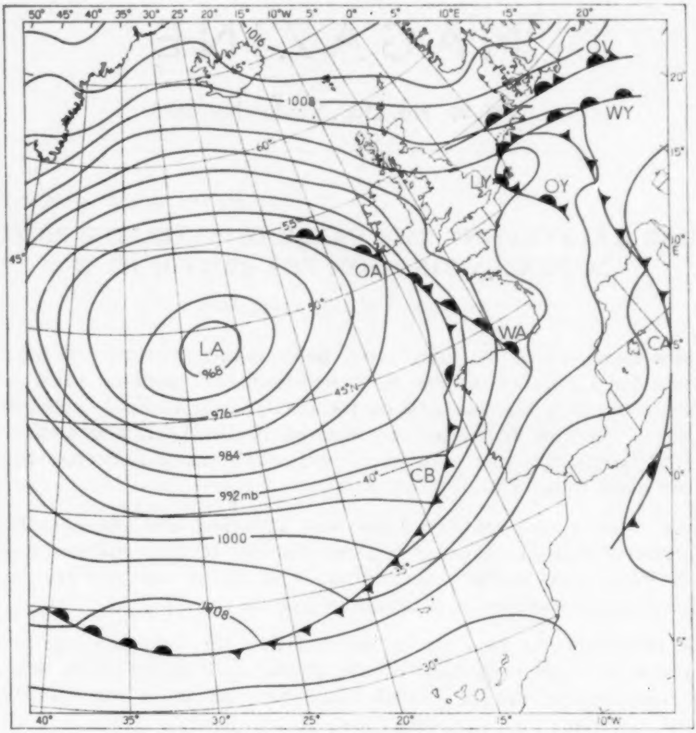

FIGURE 1—SURFACE CHART FOR 1500 GMT, 8 APRIL 1966

not many ship reports to aid in placing the cold front but it was a logical extrapolation of the position on the 1200 GMT chart which was better (though still not very well) served with ship reports. The 1800 GMT chart was initially drawn on the basis of the 1200 and 1500 GMT analyses but, at about the time the chart was being completed at CFO, a TIROS nephanalysis for 1429 GMT was received over the international facsimile network.

An outline of this cloud analysis is shown as Figure 2 together with the revised position of the cold front based on the satellite information. The cloud analysis clearly suggests that the cold front was somewhat further east in its southern portion than had been suspected and, more important, that there was a fairly well-developed wave on the cold front in the Bay of Biscay nearer to the British Isles than indicated on the original drawing of the 1500 GMT chart.

The revised 1500 GMT analysis, with subsequent time adjustments, was found to conform well with available 1800 GMT observations and the amended

analysis was used in the preparation of the surface prognosis for 1800 GMT 9 April. The line of reasoning of the forecaster is clearly indicated in the following extracts from the synoptic review issued at 2235 GMT on 8 April.

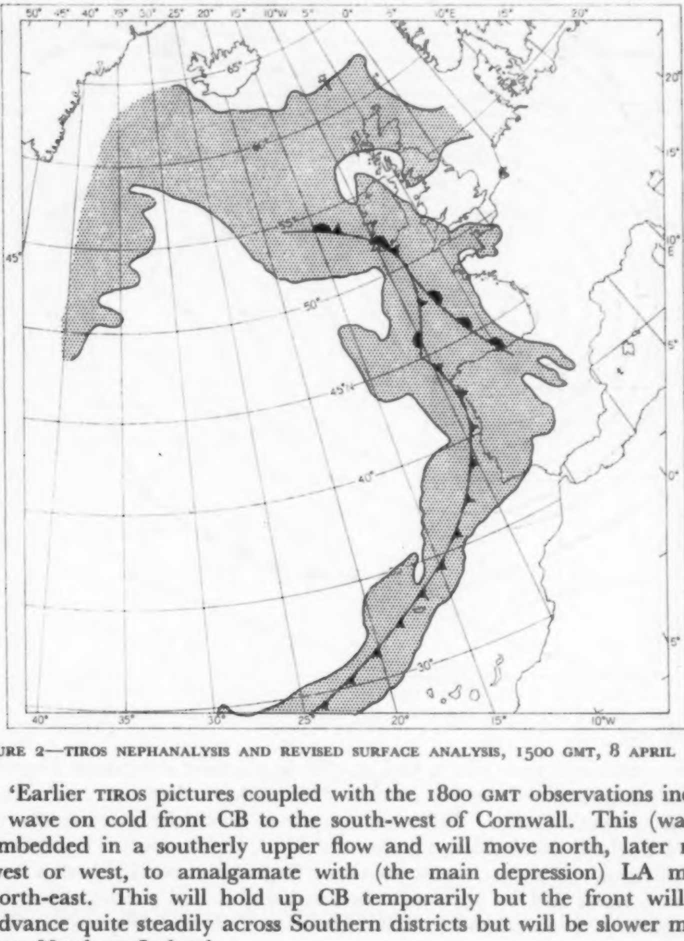

FIGURE 2—TIROS NEPHANALYSIS AND REVISED SURFACE ANALYSIS, 1500 GMT, 8 APRIL 1966

'Earlier TIROS pictures coupled with the 1800 GMT observations indicate a wave on cold front CB to the south-west of Cornwall. This (wave) is embedded in a southerly upper flow and will move north, later north-west or west, to amalgamate with (the main depression) LA moving north-east. This will hold up CB temporarily but the front will later advance quite steadily across Southern districts but will be slower moving over Northern Ireland.

The rain over South-west England and Wales is temporarily held up by a wave near Scilly but will soon begin to progress across Southern districts of England . . . By morning the rain is expected to be covering Northern Ireland, Wales, the Midlands and much of South-east and central Southern England and will move to Northern England and East Anglia during the day. Brighter weather with sunny spells and showers will follow the rain, reaching parts of South-west England by morning and most of Wales, the Midlands, central Southern and South-east England by evening.'

Figures 3 and 4 show the surface prognosis for 1800 GMT 9 April and the actual chart at that time.

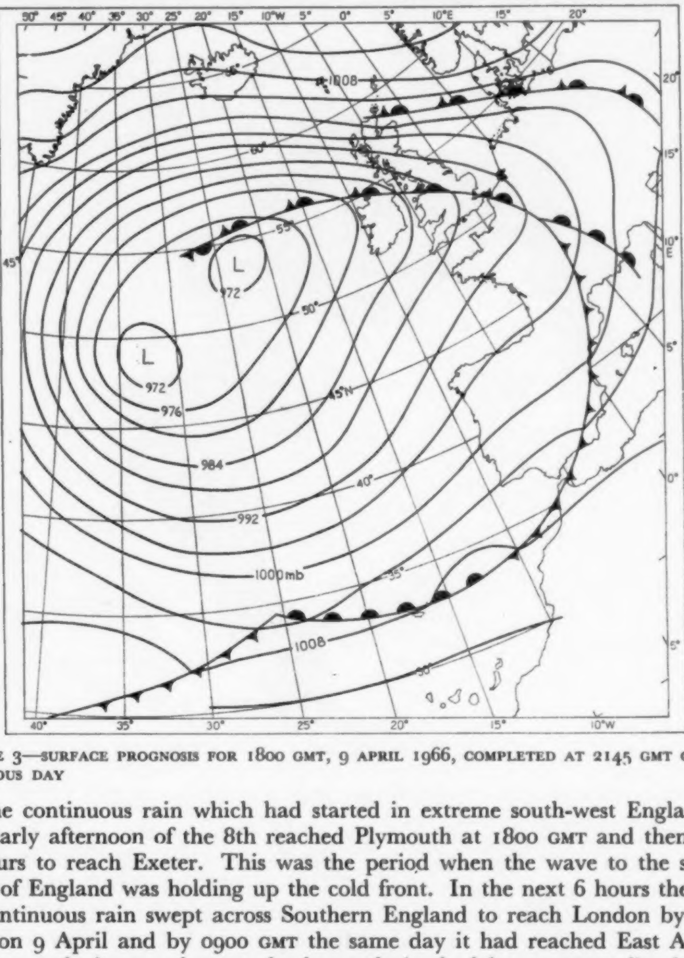

FIGURE 3—SURFACE PROGNOSIS FOR 1800 GMT, 9 APRIL 1966, COMPLETED AT 2145 GMT ON THE PREVIOUS DAY

The continuous rain which had started in extreme south-west England in the early afternoon of the 8th reached Plymouth at 1800 GMT and then took 4 hours to reach Exeter. This was the period when the wave to the south-west of England was holding up the cold front. In the next 6 hours the area of continuous rain swept across Southern England to reach London by 0400 GMT on 9 April and by 0900 GMT the same day it had reached East Anglia. Subsequently it moved more slowly north (as had been expected) with the wave moving north over Ireland and later west, reducing the northward gradient on the front.

In this case it is doubtful whether such accuracy in the forecast could have been achieved without the help of the TIROS nephanalysis.

Conclusion.—It is seen that TIROS pictures can provide help in more detailed and accurate analyses even in the region of relatively abundant observations near the British Isles. On some occasions the improved analyses are likely to lead to more accurate forecasts and this may well happen more often than is generally supposed. The above example is based on a TIROS

photograph received at CFO 7 hours after it was taken and it becomes clear that ESSA will be potentially much more useful, pictures being available for study by the forecasters 1 or 2 hours after the photographs are taken.

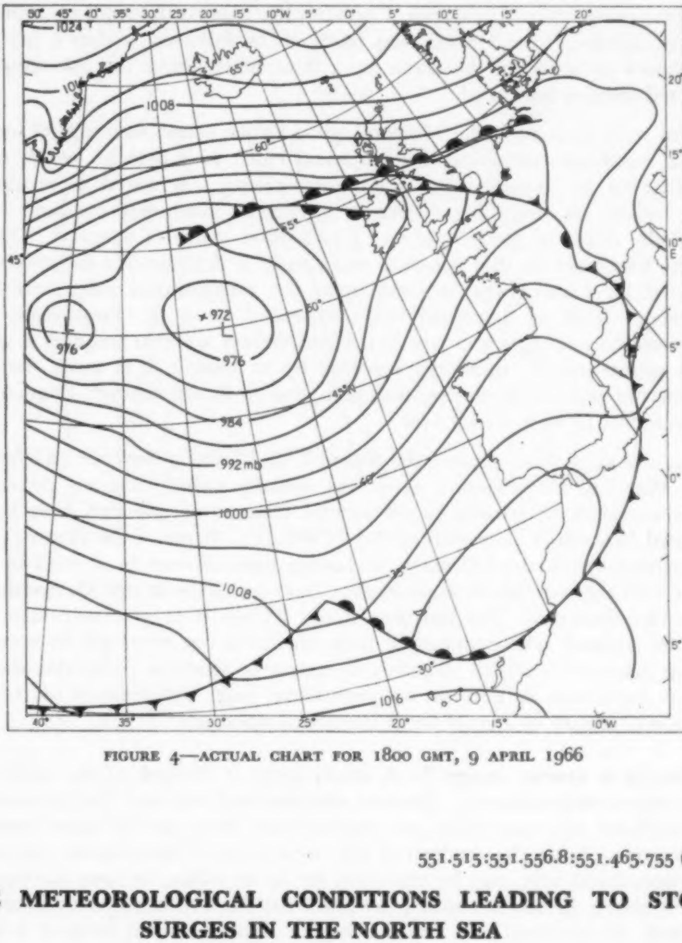

FIGURE 4—ACTUAL CHART FOR 1800 GMT, 9 APRIL 1966

551.515:551.556.8:551.465.755 (261.2)

THE METEOROLOGICAL CONDITIONS LEADING TO STORM SURGES IN THE NORTH SEA

By J. F. KEERS

Summary.—The meteorological forces which generate a storm surge are discussed from an elementary viewpoint and a simple explanation is given of how a storm surge is propagated in the North Sea. The meteorological conditions leading to storm surges in the North Sea are classified into four main types and examples are given of the effects of each of these upon the sea-level.

Introduction.—As a result of the disastrous flooding of the Thames on 6–7 January 1928 the Meteorological Office, together with the Hydrographic Department of the Admiralty and the Liverpool Tidal Institute, were requested

by the Government to undertake an investigation into the cause of such floods. The Meteorological Office had the specific task of investigating the practicability of giving useful warnings of abnormally high tides in the Thames. Dines[1] showed that the onset of a pressure gradient over a considerable part of the North Sea with a geostrophic wind of 60 mph or over from between north-west and north was likely to be followed within a period of 7–16 hours by a rise of the water by 4 ft or more above the astronomically predicted level at Southend.

From 1930 until 1953 the Meteorological Office issued warnings of meteorological conditions satisfying this empirical rule. It is perhaps worth noting here that on 31 January 1953 a danger warning was issued more than 12 hours before the 1953 flood disaster which in south-east England alone, caused the death of 350 people and £50 million worth of damage. The sea-level at Southend on that occasion was nearly 8 ft above the astronomically predicted level and, superimposed upon the astronomical tide, resulted in the danger level at Southend being exceeded by 3 ft. Fortunately such dangerous storm surges are rare but if one defines a storm surge as a raising of the astronomically predicted sea-level by at least 2 ft at more than one port on the east coast of England then one finds an average frequency of occurrence of 14 surges each year.

After the 1953 flood disaster the Storm Tide Warning Service[2] (STWS), or Flood Warning Organisation as it was initially called, was set up on the recommendation of an inter-departmental Committee presided over by the late Lord Waverley. The staff of the STWS are officers of the Hydrographic Department, Ministry of Defence, and since these officers must work in close liaison with the weather forecasters they have an office at the Meteorological Office Headquarters. The function of the STWS is to give warnings some hours in advance when unusually high sea-levels are expected to occur on the east coast of England. Before proceeding to describe particular meteorological conditions favourable for generating large disturbances of the sea-level it is necessary to answer three important questions.

What is a storm surge ?—A storm surge is defined as the difference, due to meteorological causes, between the observed tide and the astronomical tide predicted by considering the gravitational forces of the moon and sun on the earth. From the analysis of past tidal records these forces, and hence the astronomical tide, can be predicted for as far ahead in time as required. Figure 1 shows the astronomically predicted tide for Southend on 10 December 1965 and the observed tide which is higher than predicted because a storm surge occurred near to the time of predicted high water. The observed tide was recorded by a tide gauge installed at the end of Southend Pier. The tide gauge measures the height of a float free to rise and fall inside a well which allows water to pass through a restricted hole in its base ; the size of the restriction is chosen so as to remove the ordinary wind waves from the recording. Plotted below in Figure 1 is the storm surge profile with time, i.e. the difference between the astronomically predicted tide and the observed tide. A very important point is that not every storm surge results in flooding. This is because not every storm surge coincides with astronomically predicted high water and even if it did flooding would not occur unless the surge was

unusually large or unless the astronomical tide was unusually large, as for instance at the time of the high spring tides associated with a new or full moon.

In order to track the surge as it travels along the east coast there are seven distant-recording tide gauges situated at the following places: Wick,

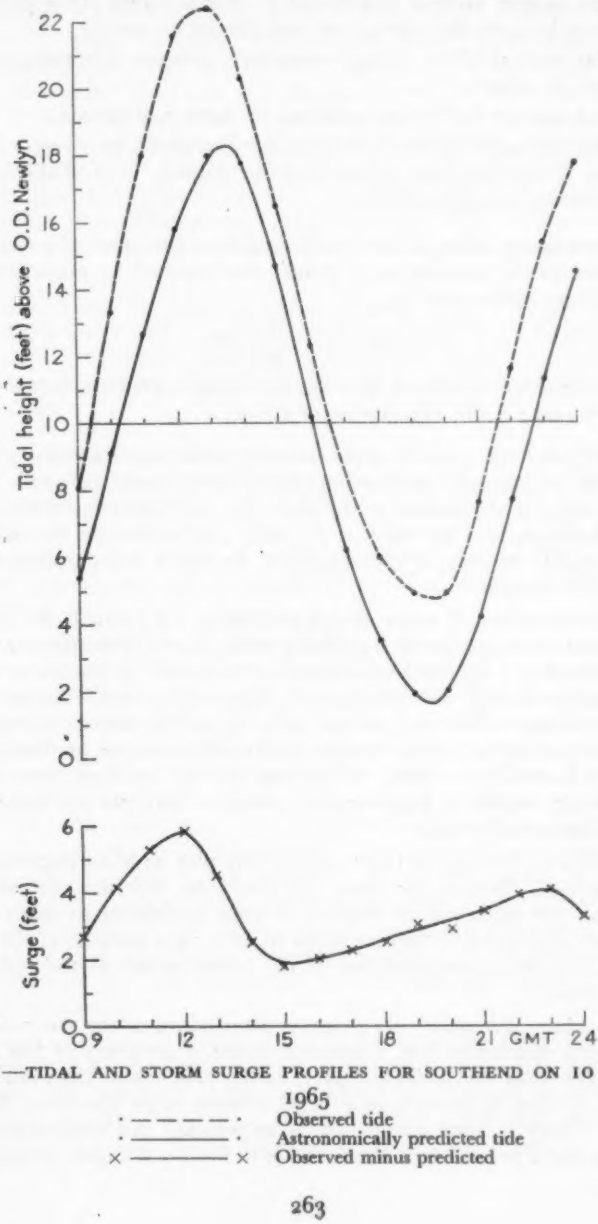

FIGURE 1—TIDAL AND STORM SURGE PROFILES FOR SOUTHEND ON 10 DECEMBER 1965

· — — — — · Observed tide
· ———— · Astronomically predicted tide
× ———— × Observed minus predicted

Aberdeen, Tyne, Immingham, Lowestoft, Harwich and Southend. The tide gauges are connected to recorders at the Storm Tide Warning Service at Bracknell by GPO telegraph lines and give a continuous, up-to-the-minute, record of the sea-level.

How are storm surges generated ?—Storm surges are a direct result of interaction between the atmosphere and the sea by way of :

(i) The statical effect of the atmospheric pressure depressing or raising the sea surface.

(ii) The tractive force of the wind on the surface of the sea.

(iii) The propagation of the disturbance introduced by (i) and (ii) under the dynamical laws controlling the motion of a shallow layer of water on a rotating globe.

Static pressure effect.—For steady conditions the effect of a change from normal atmospheric pressure is to disturb the sea-level by an amount given by the ordinary hydrostatic law,

$$\mathrm{d}h = -\frac{1}{\rho g}\,\mathrm{d}p$$

where h is the depth of the sea, p is the atmospheric pressure, ρ is the density of sea water and g is the acceleration of gravity.

Wind effect.—The growth of the ordinary wind waves and the generation of wind driven currents are inseparable features associated with a strong wind blowing over the surface of the sea. The accepted relationship between the shearing stress, τ, of the wind on the surface of the sea and the wind speed, V, is $\tau = k\rho_a V^2$, where ρ_a is the density of air and k is a parameter usually taken to be a constant.

Mass transportation of water occurs because of sea currents but in certain circumstances it also occurs with ordinary wind waves. The effect of the wind on the sea-level of a confined sea or channel is to pile up the sea at one end, as for example during an easterly wind blowing up the Thames Estuary. In the equilibrium state a return flow is set up in the bottom layers and the slope of the sea surface is such that the hydrostatic pressure gradient balances the tractive force of the wind. If the sea is not confined then on-shore winds blowing against a long straight coastline may set up horizontal as well as vertical circulations.

Winds blowing parallel to the coastline may also have an important effect on the sea-level. Indeed the most effective wind direction for raising the sea-levels on the east coast of England is from north-west to north. This is because the wind-induced current tends to turn right because of the Coriolis force and thus mass transportation of the water occurs to the right of the wind direction.

So far we have discussed only positive disturbances of the sea-level. Winds from between south-east and south-west cause a lowering of the sea-level along the east coast and although the lowering effect alone does not threaten flooding it is often a prelude to a large positive surge travelling down the east coast. There is some speculation as to whether this oscillatory effect is due to the natural period of the North Sea or to the fact that gale force southerly

winds are usually associated with a depression moving eastwards across the British Isles and bringing north-westerly winds into the North Sea behind it.

Dynamic effects.—Once a surge, however small, has been generated it will be propagated according to certain laws of wave motion. Provided that the wavelength is much greater than the depth of the sea, which in turn is much greater than the amplitude of the wave, then the speed of propagation of the wave is $(gh)^{\frac{1}{2}}$. To explain the dynamic effect let us suppose that the meteorological forces move at a speed v, which is less than the phase speed, $(gh)^{\frac{1}{2}}$, of the surge. The newly developed surge will move ahead of the meteorological forces and tend to decay unless other effects, such as the convergence of an estuary or the gradual decrease in the depth of the sea, cause it to do otherwise. On the other hand if the meteorological forces move at a speed equal to the phase speed of the surge then the surge will be building up throughout its progression and be in resonance with the forces. Another type of resonance occurs when the period of the surge is equal to the natural period of the sea.

In the North Sea the surge travels at a speed $(gh)^{\frac{1}{2}}$ only near the coasts, and in shallow water with a mean depth of 120 ft this speed is approximately 37 kt so that a depression travelling at about this speed in a south-easterly direction would induce a relatively large amplitude because of the dynamic effect involved.

How is a storm surge propagated ?—In order to explain what happens to a surge once it has been generated let us consider a rectangular basin of water oscillating in the fundamental mode related to the length and depth of the basin. If the basin is not rotating, i.e. if there is no Coriolis force, then the water will oscillate from one end to the other and the level will remain unchanged along a line called the nodal line. The oscillation will therefore be a standing wave.

If we now introduce the Coriolis force by imagining a basin rotating with the earth a standing oscillation will be replaced by a progressive wave travelling anticlockwise around a central nodal point, that is a point at which the sea-level remains unchanged. One form of progressive wave which can be propagated in a rotating basin is a Kelvin wave, in which the amplitude increases towards the right of the direction of propagation. The pressure gradient thus balances the Coriolis force due to the earth's rotation. Darbyshire and Darbyshire[3] showed that in the case of a rotating rectangular basin with one open end the waves can proceed from the open end down one side, then round the closed end and up the other side. The North Sea can be considered as such a basin, or better still as two basins ; a large one in the north and another taking in the Flemish Bight. Storm surges, and the astronomical tide which is also a long-wave disturbance of the sea-level, are therefore propagated southwards down the east coast before turning left and affecting the Dutch and German coasts.

A number of empirical formulae, which are useful forecasts of surge height for at least four hours ahead, depend on the southward propagation of long waves down the east coast of the North Sea ; the forecast surge heights are based on the heights observed at stations further north with allowances for local winds, both observed and forecast, and other local effects.

The meteorological conditions.—The meteorological conditions leading to storm surges in the North Sea can be classified into four basic types :

Type I :	A depression moving northwards or north-eastwards over the relatively shallow waters of the continental shelf to the west of the British Isles.
Type II :	A depression travelling eastwards, south-eastwards or southwards over the North Sea.
Type III :	A steady north-westerly wind over the North Sea.
Type IV :	Easterly or north-easterly winds associated with a depression over the southern North Sea or further south.

The surge associated with the conditions of Type I is called an external surge whereas the surges associated with the other basic types are called internal surges, i.e. generated wholly within the North Sea. Most storm surges in the North Sea are a combination of internal and external surges, that is they are caused by a combination of the four basic types of meteorological conditions.

Example of Type I conditions and associated surge.—The storm surge of 15–16 October 1963 was caused by a meteorological disturbance of Type I. The meteorological situation at 1200 GMT on the 15th and 0600 GMT on the 16th is shown in Figure 2, and the resultant surge profiles recorded by the tide gauges on the east coast are shown in Figure 3. The surface winds in the North Sea were never veered north of west and consequently it can be assumed that they played no part in raising the sea-levels on the east coast ; this is not always the case. The surge was propagated according to elementary

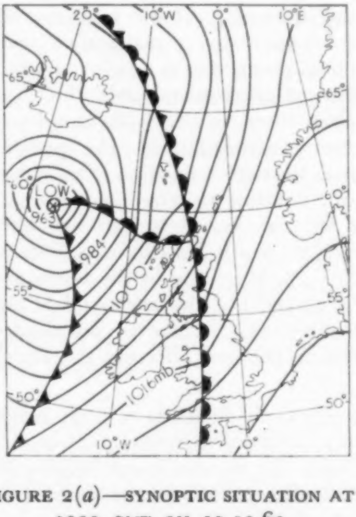

FIGURE 2(*a*)—SYNOPTIC SITUATION AT 1200 GMT ON 15.10.63

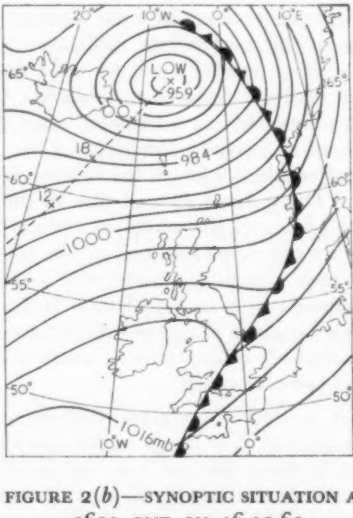

FIGURE 2(*b*)—SYNOPTIC SITUATION AT 0600 GMT ON 16.10.63

theory and the surge profile remained almost unchanged. The decay of the surge due to frictional forces was balanced by the effects of the gradual decrease in the depth of the sea as the surge was propagated southwards. The surge on this occasion is a good example of an external surge.

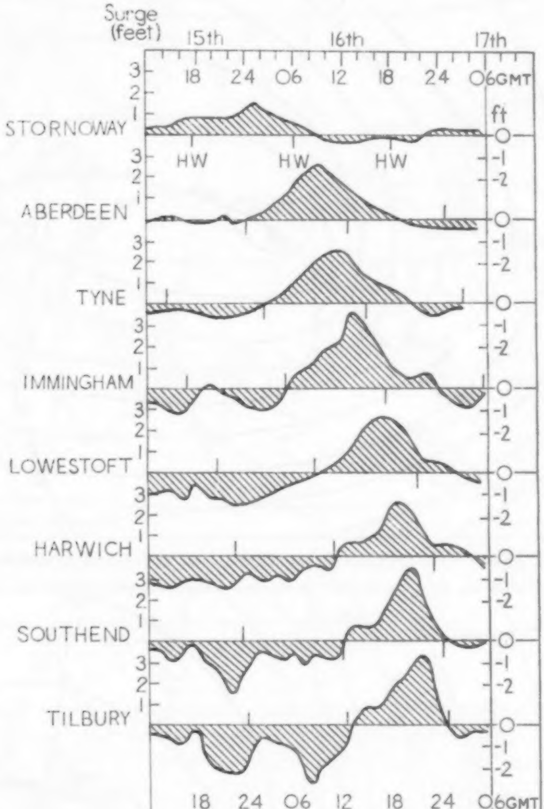

FIGURE 3—SURGE PROFILE DIAGRAM OCTOBER 1963
Vertical dash indicates the time of High Water (HW)

An example of a combination of Type I and Type II conditions and the associated surge.—The most dangerous type of meteorological conditions for the raising of the sea-levels on the east coast is a combination of Type I and Type II conditions. (It was such a combination which led to the disastrous flooding on 1 February 1953. Detailed accounts of this storm surge and the associated meteorological conditions are plentiful[4,5].) The meteorological developments on 9 and 10 December 1965 were of Type I and II. The resultant surge on this occasion was caused by a deep low and its associated trough which moved south-eastwards across the North Sea,

see Figure 4. A definite sea-level pulsation due to a cold front and trough moving across the North Sea was recorded by the tide gauges at Immingham,

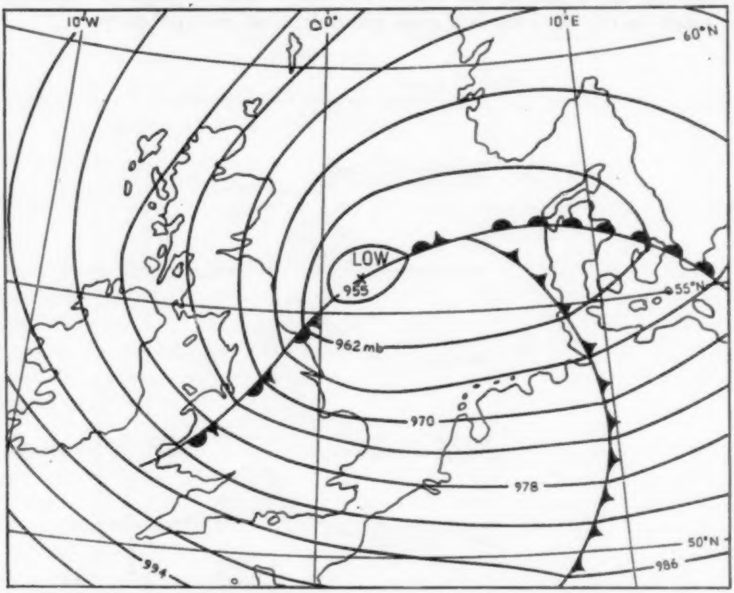

FIGURE 4(*a*)—CFO ANALYSIS FOR 0000 GMT ON 10 DECEMBER 1965

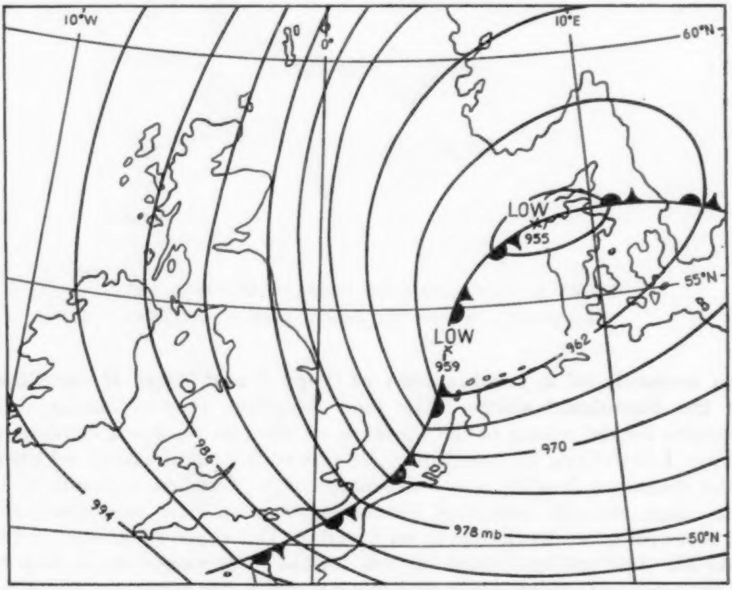

FIGURE 4(*b*)—CFO ANALYSIS FOR 0600 GMT ON 10 DECEMBER 1965

Lowestoft, Harwich and Southend. Figure 5 shows the variation of the geostrophic wind component along 360 degrees for an area covering most of the Flemish Bight and the resultant pulsation of the sea-level at Southend.

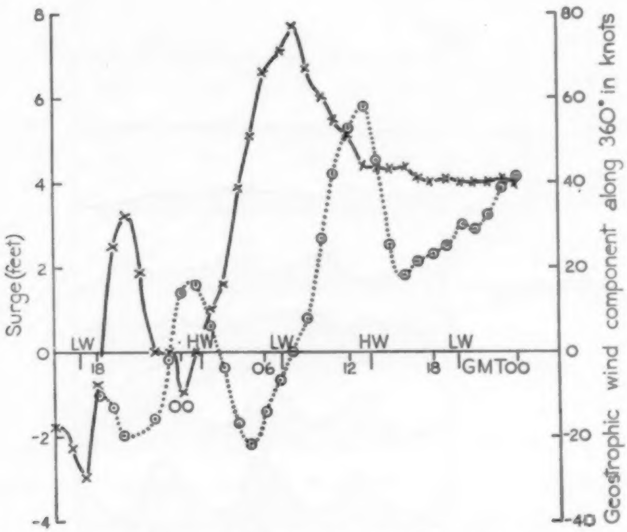

FIGURE 5—ASSOCIATION BETWEEN SURGE AT SOUTHEND AND MEAN GEOSTROPHIC WIND MEASURED OVER AN AREA OF THE FLEMISH BIGHT ON 9–10 DECEMBER 1965

× —— × —— × Geostrophic wind component along 360° ; ⊙ . . . ⊙ . . . ⊙ Southend surge
HW = High Water LW = Low Water

The average speed of movement of the trough as it moved south-eastwards was approximately the same as that of the astronomical tide travelling down the east coast. Therefore large dynamic effects were present and the meteorological disturbance and astronomical tide were in phase so as to cause a large disturbance at the time of astronomically predicted high water The lag of 5 hours between the maximum effective wind over the Flemish Bight and its effects upon the sea-level at Southend is mainly due to the delayed effect of the Coriolis force and the time the disturbance takes to travel to Southend. It is interesting to note that the storm surge which caused the Thames to be flooded on 6 January 1928 was due to a meteorological development analogous to that of 10 December 1965.

Example of Type III conditions and the associated surge.—Steady winds from the north-west raise the sea-level as a whole, perhaps for two or three days at a time but there is a strong tidal disturbance in these cases, a marked and persistent semi-diurnal oscillation being prominent in the storm surge profile. The tidal disturbance is caused by interaction between the surge and the astronomical tide and is most pronounced at the shallow water ports with a large range of tide.

On 11 and 12 October 1960 the winds were gale force north-westerlies over most of the North Sea and the resultant surges affecting the east coast are shown in Figure 6. The effect of interaction at Lowestoft, where the range of the astronomical tide is small, is much less than that at, say, Southend.

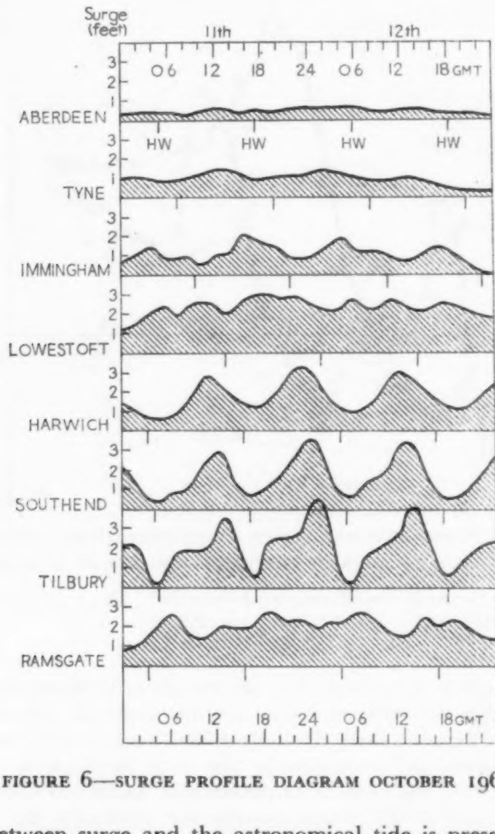

FIGURE 6—SURGE PROFILE DIAGRAM OCTOBER 1960

Interaction between surge and the astronomical tide is present to a greater or lesser extent in all the surges which travel down the east coast but observational evidence suggests that interaction is least when the surge and the meteorological forces are moving at the same speed, i.e. resonating.

Examples of Type IV conditions and associated surge.—An example of an internal surge is the storm surge of 25 February 1958 which was caused by meteorological conditions of type IV, see Figure 7. A depression moved eastwards across southern England and the Flemish Bight and the winds in the North Sea were gale force north-easterlies backing northerly later. The surge associated with these meteorological conditions is shown for Sheerness in Figure 8 (pecked line) together with the wind component along 350 degrees (full line). There was a correlation coefficient of 0·92 between the wind speed and the height of the surge on this occasion. There was an equally

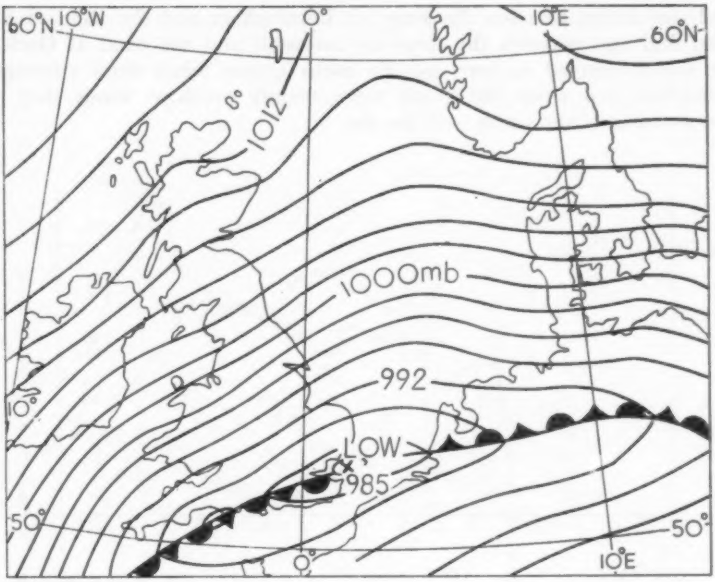

FIGURE 7(*a*)—CFO ANALYSIS FOR 0600 GMT ON 25 FEBRUARY 1958

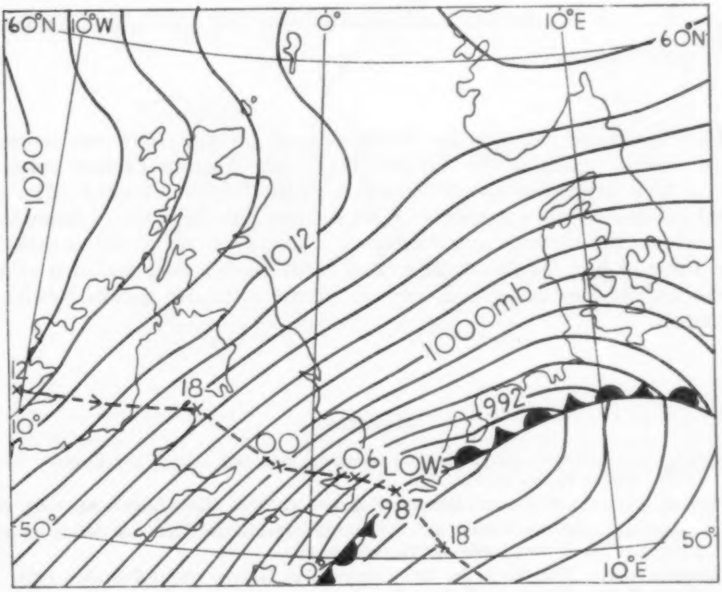

FIGURE 7(*b*)—CFO ANALYSIS FOR 1200 GMT ON 25 FEBRUARY 1958

good correlation between the surge at Immingham and the wind at Spurn Head and also between the surge at Lowestoft and the wind at Gorleston. The winds referred to here are the mean hourly winds from anemograph tabulations and since the winds were mainly on-shore winds they were representative of the winds over the sea.

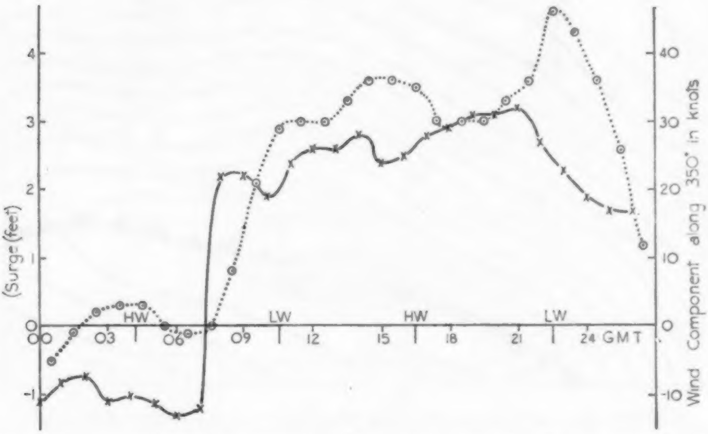

FIGURE 8—ASSOCIATION BETWEEN WIND AND SURGE AT SHEERNESS ON 25 FEBRUARY 1958

× —— × —— × Shoeburyness wind component along 350° ; ⊙ . . . ⊙ . . . ⊙ Sheerness surge

HW = High Water   LW = Low Water

The calamitous surge in the Thames on 18 January 1881 was caused by severe easterly gales in the Flemish Bight and Thames Estuary associated with a deep depression almost stationary in the English Channel. The wind speed reached a mile a minute at Kew and was gale force for 15 hours in all. The tide on this occasion was the highest Thames tide on record at that time. The surge of 6–7 January 1928 caused a still higher tide, and that of 1953 is the highest now on record, 15·1 ft. (above ordnance datum Newlyn) at Southend.

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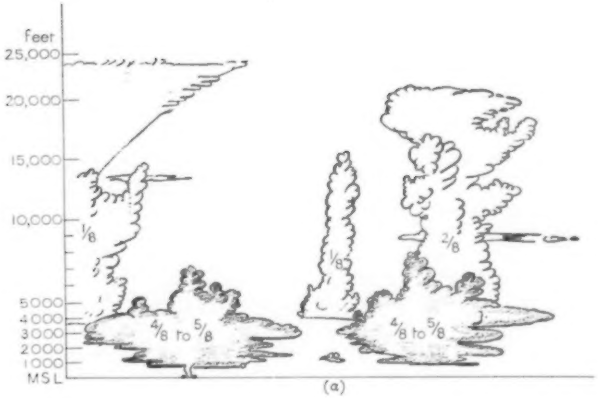
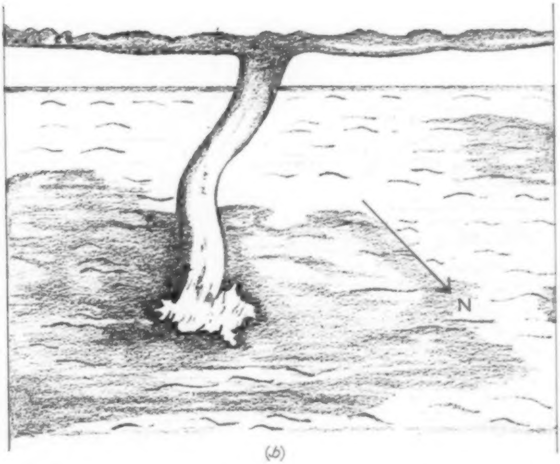


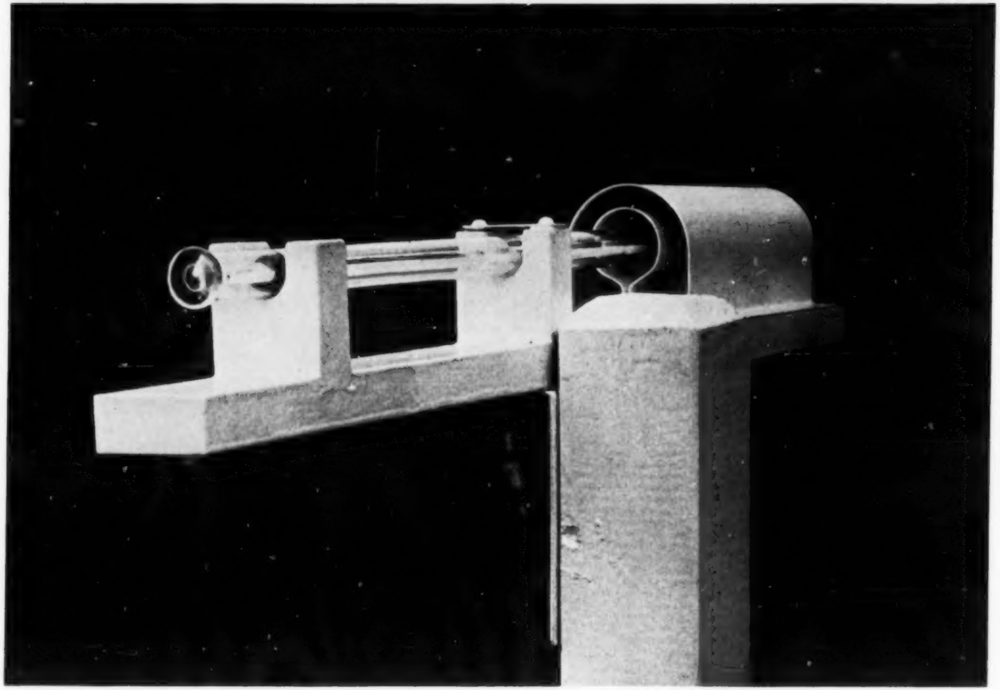
(*a*)



(*b*)

PLATE I—(*a*) WATERSPOUT AND CLOUD DISTRIBUTION 10 MILES SOUTH-WEST OF SUMBURGH HEAD SHORTLY AFTER 1535 GMT, 22 NOVEMBER 1965 (*b*) DETAILS OF THE WATERSPOUT FROM A SKETCH PROVIDED BY THE AIRCREW.

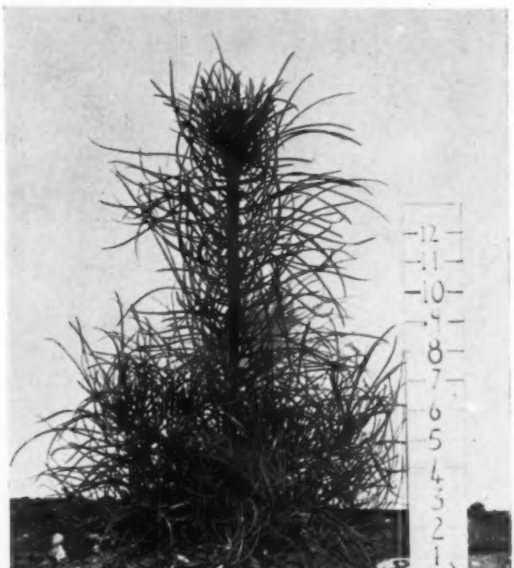
It was reported by the Captain that the waterspout was 'very similar to photographs I have seen of tornadoes, though somewhat less trailing'.



Photograph by courtesy of Forestry Commission

PLATE II—COCOA-TIN THERMOMETER MOUNT (see page 274)

(*a*) Sapling grown in grass-covered soil



Photographs by courtesy of Foresty Commission

(*b*) Sapling grown in bare soil

PLATE III—TWO CORSICAN PINE SAPLINGS IN THETFORD CHASE, SHOWING THE GREATER EFFECT OF FROST DAMAGE ON THE SAPLING GROWN IN GRASS-COVERED SOIL THAN ON THE SAPLING GROWN IN BARE SOIL

Both trees were planted two years ago (see page 277)

To face page 273

Photograph by S/Ldr B. Jenkins, RAF

PLATE IV—CUMULONIMBUS WITH STREAMING ANVIL

The photograph was taken at Butterworth, Malaysia in January 1966 looking south-west towards the Malacca Straits and Sumatra. This photograph may be compared with the streamer shown facing p. 80 in the *Meteorological Magazine* for March 1966.

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TEMPERATURES IN THE FOREST OF THETFORD CHASE

By G. W. HURST

Summary.—Young Corsican pine has been lost recently in Thetford Chase because of frosting, and this paper describes a minimum temperature investigation to find the factors involved. Conclusions emerged that planting over bare soil would reduce frost risk, but that the size of the clearing did not appear very significant. No significant difference appeared to exist in the incidence of late spring frosts in the last few years compared with that of the 1920's when Corsican pine was first (successfully) introduced.

Introduction.—An examination has been made, in conjunction with Forestry Commission research pathologists, of temperatures in different places and exposures in Thetford Chase, Suffolk. The investigation was started because newly planted Corsican pine was being lost where it had previously been established and grown for about 40 years. This loss is potentially serious, because if the replacement of Corsican pine by Scots pine were enforced upon the Forestry Commission, the quantity of timber per acre would fall by about 25 per cent.

Symptoms of frost damage to the young Corsican pine shoots were observed, and in both 1964 and 1965 experiments were carried out with thermometers exposed at heights of 4 feet and 6 inches in a number of different sites and exposures. A vertical sounding from 2 in to 6 ft above ground was made in one place. This paper is concerned with a comparison of temperatures at 4 ft and 6 in in 1965, with cross-reference to 1964 results as necessary.

Sites.—It is not worthwhile to discuss in full detail all the sites which were used, and site plans are not given with this paper. The notes below are sufficient to give a general indication of the characteristics of the various sites. Dimensions quoted relate to areas contained within surrounding forest, which is mostly composed of trees in the height range 25–40 ft. Thermometers were installed at heights of 4 ft and 6 in unless otherwise stated.

Harling Nursery. This was a fairly large open area mostly covered with bare earth, approximately 8 acres in extent. Proneness to air stagnancy would not be expected. The thermometers were exposed in the middle of the nursery, from which position there was a very slight down slope to the west.

Harling. This was a very large clearing about 500 by 700 yd (70 acres) and flat, but it contained many small trees or even miniature coppices, and the air tended therefore to be very stagnant. Three thermometer positions were established, one over forest litter, one over rough grass and one over a square chain of bare soil. There appeared to be no obvious difference in the general exposure of the three positions chosen.

Lynford. This was a fairly large clearing about 300 by 450 yd (some 25 acres), with a slope of about 1° downwards to the north. The ground surface in 1965 was rough grass, but had been mainly litter covered in 1964. Two 4-ft thermometer positions were chosen here, one in the centre and one in the low north corner. A 6-in thermometer was exposed at the central site only.

Mundford. This was another fairly large clearing, 200 by 400 yd (about 17 acres), in which thermometers were exposed in three places, the centre,

near an edge and halfway between in 1964, but only in the central position in 1965. Mundford was the area chosen for the vertical sounding from 2 in to 6 ft.

West Tofts. This was a long narrow clearing 80 by 250 yd (4 acres) with a slight upslope of ½–1° from west to east, the length of the clearance. The ground was rough grassed and thermometers were exposed at 6 in at the centre and also at 4 ft near the western and eastern ends.

Santon Nursery. This clearance was very small, 70 by 35 yd (½ acre) and thermometers at 4 ft and 6 in were placed near the centre.

Kings. This lies to the south of the main part of Thetford Forest, and thermometers were put here to obtain temperatures representative of the most open part within the Forestry Commission area, as there were several hundred acres of open, fairly level, unwooded land.

Exposure of thermometers.—The 4-ft thermometers were exposed in cocoa-tin mounts (see Plate II), but the 6-in thermometers were without protection. The cocoa-tin mount is one used specially for obtaining minimum temperatures cheaply at a number of different points in the same area. The thermometer is held horizontally and firmly by being clipped in at two support points. For protection against direct radiation the bulb is placed inside a roughly cylindrical shield open at each end. The shield has double walls which are made of metal and are separated by an air space. The shield and mount are painted white. Although previous comparisons have been made, a special comparison was made of the minimum temperatures obtained from the screen at Grime's Graves, the agromet station within the Thetford Chase area, and those obtained from a shielded 4-ft thermometer placed near the screen. The comparison showed that

$$T_s = T_m + 1{\cdot}0 + 0{\cdot}2T$$

where T_s = 24-hour minimum temperature in °F with conventional screen exposure, T_m = 24-hour minimum temperature with cocoa-tin exposure, T = difference between screen and grass night minimum temperatures. It was assumed that this correction ($1{\cdot}0 + 0{\cdot}2T$) could be applied to T_m everywhere in the forest area to give an estimate of the screen temperature T_s.

Frost frequencies defined by years in 10.—A comparison is made between 4-ft corrected temperatures and those at a long-term standard station to arrive at a frequency of years in 10 when a frost can be expected. The long-term station nearest to Thetford is the airfield at Mildenhall, where acceptably homogeneous records (based on a good open exposure) have been maintained for many years. It has therefore been used for the comparison. The lowest, second lowest and third lowest temperatures (i.e. effectively minima on radiation nights) each week for each station separately are compared with similar figures for Mildenhall. Departures of the experimental stations from the standard station enable the long-term averages for the latter to be used to yield figures of the number of years in 10 when temperatures 32°F and 28°F will occur at the experimental stations from the various weeks from 1 April to 26 May (Smith[1]) ; a similar technique was extended by the author to cover June.

It is not worth quoting here figures for both criteria, and Table I gives the numbers of years in 10 when temperatures below 28°F might be expected in April, May and June ; the lower criterion was selected because of the greater spread in readings, and because the Forestry Commission pathologists considered 28°F to be a more critical temperature for potential frost damage than 32°F.

TABLE I—FROST RISK, EXPRESSED AS YEARS IN 10 WITH SCREEN TEMPERATURES FALLING BELOW 28°F ON OR AFTER DATES SHOWN

Week commencing	Site: Harling				Lynford		West Tofts			Others			
	A	B	C	D	E	F	G	H	I	J	K	L	M
1 April	10	10	10	10	10	10	10	10	10	10	10	10	8
8	10	10	10	10	10	10	10	10	10	10	10	10	7
15	9	10	10	10	10	10	10	10	10	10	10	9	6
22	9	10	10	10	10	10	10	10	10	10	10	9	5
29	9	10	10	10	10	10	10	10	10	10	10	8	3
6 May	8	10	10	10	8	10	10	9	9	9	10	5	1
13	7	10	10	10	7	9	9	9	9	9	10	4	0
20	4	9	8	6	3	9	6	5	8	7	8	2	0
27	2	5	6	3	*	*	3	3	4	4	4	1	0
3 June	1	3	3	2			2	2	3	2	2	+	0
10	0	1	2	1			1	1	1	1	1	0	0
17	0	+	1	+			+	+	+	+	0	0	0
24	0	0	+	0			0	0	0	0	0	0	0

+ indicates 0·1 to 0·4   * thermometer not available from early June

The sites are :

A Harling Nursery
B Harling (over grass)
C Harling (over litter)
D Harling (over bare soil)
E Lynford (centre)
F Lynford (corner)
G West Tofts (west end)
H West Tofts (centre)
I West Tofts (east end)
J Santon Nursery
K Grime's Graves
L Kings
M Mildenhall

Notes : Mundford 4-ft. thermometer became increasingly and demonstrably in error during the period, and its results are therefore not quoted above. Figures for this table were worked out to the nearest decimal point, but to indicate the order of accuracy involved they have been rounded to the nearest whole number.

Several striking points are seen in this table. In the stagnant Harling area at the end of May a 50 per cent chance still exists of moderate frost over grass or litter, and the lower risk over bare soil can be seen from May onwards. The Lynford figures are incomplete (the thermometers were stolen early in June) but the greater coldness of the low corner is obvious. Differences in the West Tofts sites are not large, and may perhaps lie in the thermometers themselves and not in site characteristics. Possibly the wider approach rides in the east compared with those in the west may have facilitated the penetration of cold air. Santon Nursery (and Grime's Graves) are obviously frost-prone sites, only a little better than the vegetative covered Harling, but the freedom from late moderate frosts at Kings and especially at Mildenhall contrasts with the other sites.

A similar analysis was made using the 1964 data, and a comparison was possible for several of the stations. That year, like 1965, was comparatively frost free, but the technique of obtaining years in 10 of frost risk gave very comparable results. If anything, however, Table I probably fails safe, with some overstatement of frost risk in Thetford Chase especially if there is an increase in windiness in late spring.

Comparison of 4-ft thermometers with Mildenhall temperatures.—The difference between the minimum temperatures at the various sites and at Mildenhall was averaged for each week of the 13 weeks from 1 April to 30 June, and as an illustration Figure 1 shows the weekly average differences for Harling Nursery and for Harling over bare soil and over grass. It is clear that Mildenhall is warmer than Harling Nursery and much warmer than the other two Harling sites, but an interesting feature is that the difference between the stations and Mildenhall is conspicuously smaller in weeks 3 and 9 than in the other weeks. Examination of the data over the three-month period showed that these were two weeks with limited radiation.

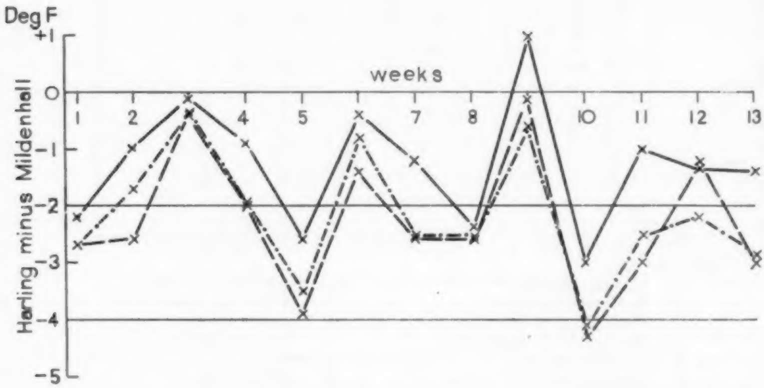

FIGURE 1—WEEKLY AVERAGE DIFFERENCES IN MINIMUM TEMPERATURE AT A STANDARD HEIGHT OF 4 FT BETWEEN HARLING SITES AND MILDENHALL, 1 APRIL—30 JUNE 1965

——— Harling (Nursery) ; — — — Harling (over bare soil) ;
—·—·— Harling (over grass)

There is a correlation coefficient of –0·73 between (*a*) the overall average for Thetford Chase stations minus Mildenhall and (*b*) the weekly difference between maximum and minimum temperatures for Mildenhall. This correlation supports the theory that when there is little difference between maximum and minimum temperatures (i.e. the weather is mostly dull) the spread of minimum temperatures at the sites themselves is less than on clear nights. It is also probably fair to conclude that the big open sites, Harling Nursery, Kings and Lynford are relatively warm at night compared with the ill-drained and more stagnant areas such as Harling, Santon Nursery and West Tofts. It is worth adding that Oliver[2] has found Grime's Graves in many respects the coldest meteorological station below 1000 ft in Britain. He quotes data showing it conspicuously cold in the summer months, and remarks that there is no month completely free of frost ; the lowest known recorded June temperature in Britain of 22°F occurred at Grime's Graves on 1 June 1962. Grime's Graves is an irregular 40-acre clearing in the forest, and the thermometer enclosure is almost at the bottom of a frost hollow.

Thermometers exposed at a height of 6 in.—Thermometers were exposed at 6 in above ground (with vegetation kept fairly well down) on wooden supports with no attempt at bulb shielding. The thermometers were also left out for 24 hours, read at 0900 GMT only, and were equipped with black sheaths over the stem to prevent condensation of spirit on the walls of the tube. Much the same set of sites was used for these readings as for those at 4 ft. Only during April and May were observations at 6 in taken at Mildenhall, which could therefore not be used as a standard. Instead, the open Kings site was used, and Figure 2 shows the difference between temperature at 6 in there and at Harling Nursery, Harling over

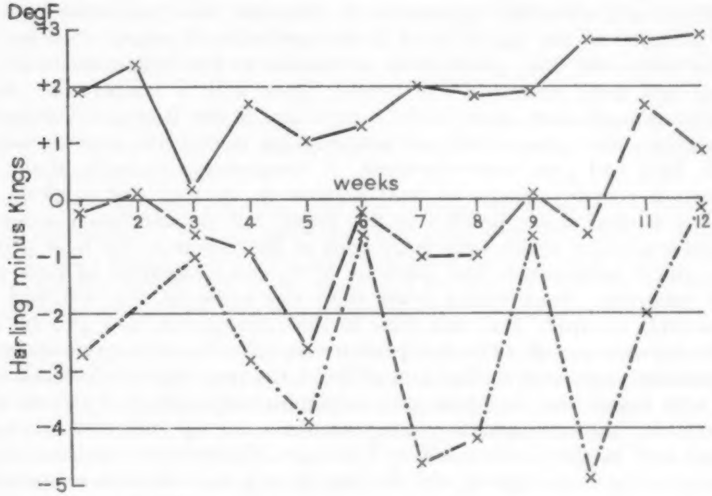

FIGURE 2—WEEKLY AVERAGE DIFFERENCES IN MINIMUM TEMPERATURE AT A HEIGHT OF 6 IN BETWEEN HARLING SITES AND MILDENHALL, 1 APRIL—23 JUNE 1965

———— Harling (Nursery) ; — — — Harling (over bare soil) ;
—·—·— Harling (over grass)

grass and Harling over bare soil. This is the same selection of sites as in Figure 1, but the differences are dramatically greater. At 6 in, the bare-soil thermometer of Harling Nursery gives a higher temperature than Kings throughout the entire period (restricted to 12 weeks because of much thermometer trouble in the last week) and the difference in character between the grass cover and the small bare soil patch at Harling itself is striking. Equally arresting was the spectacle of two similar saplings, planted about two years earlier and seen in Plate III. The one planted in bare soil was thriving and doing well and the other with a grass carpet was stunted with obvious frost damage. Root competition may have been a factor, but the forest pathologists thought lack of frosting was the main reason for the excellent progress over bare soil.

A further factor controlling growth may possibly have been the lower average soil temperature under grass compared with bare soil. As an indication of the dimensions involved, Rider[3] found that in May and June 1954 the average difference between daily maximum temperatures 2 in below soil and 2 in below short grass cover was + 4·2 deg.F, and the corresponding difference in minimum temperatures – 1·8 degF, giving an average temperature below bare soil 1·2 degF higher than under short grass. The average difference in temperature under the clay near Cambridge becomes small at depths of a foot or more.

Temperatures now and at first planting.—The recent trouble in establishing Corsican pine in Thetford Chase has arisen in areas being replanted, and a possible explanation of difficulties now compared with the first plantings in the 1920's could lie in some climatic change between the earlier years and now, particularly in relation to low temperatures in late spring and early summer. The nearest place with a temperature record running through from 1920 to the present day is the Botanical Gardens at Cambridge, and grass minimum temperatures during the critical months April, May and June were examined. A comparison was made of the frequency of varying degrees of frost severity in 1921–30 and 1958–65. A detailed analysis is not justified in this paper, but the conclusion seems inescapable that the 1920's were every whit as frost prone as the later period. The critical temperature was taken as 28°F, and frequencies of days with grass minimum temperatures lower than this averaged 7·4, 1·8 and 0·1 respectively in April, May and June of the early period, and 4·6, 1·6 and 0·3 for the same months of the late period. Averages of extreme grass minimum temperatures were very similar, and although the year 1962 was exceptionally cold with lowest May and June grass minimum temperatures of 20 and 24°F respectively, the corresponding temperatures were 24 and 26°F in 1923, 21 and 29°F in 1927 and 22 and 29°F in 1921. Only on two occasions (both in 1962) in the years 1958–65 did the May/June grass minimum temperature fall below 24°F, compared with four occasions in 1921–30 (all separate years).

Further experimental work.—More experiments are being conducted during 1966 partly to confirm results already obtained and partly to try out one or two different ideas. Two thermometers are being placed in the Battle Area, a large open space controlled by the Ministry of Defence (Army), but within the general forest boundaries ; and a second vertical array of thermometers will be erected, providing data over bare soil as well as over grass. It is hoped that during the season very narrow strips will be cleared, and an assessment can then be made of the potential advantages, if any, of such very narrow strips.

Conclusions.—To some extent this must remain an interim report, as modified experiments are being made again this year, and probably will be made next year also. Some points can, however, be made with little fear of major error.

(i) The nature of the ground cover appears to be a very important factor in determining the frequency, intensity and duration of frost. The Harling sites bring this out very clearly as the small 16-perch bare patch showed markedly less frost at 6 in than over the nearby grassed area.

It is probable that this island of 16 perches is insufficient in size to reflect itself in the temperature at 4 ft, but the difference in character between Harling Nursery and Harling may well be mostly a function of the absence or presence of a grassed surface.

(ii) There seems little advantage in making particularly small clearings in forests. Two such were introduced during the experiment, near Santon Nursery and at West Tofts, and they were among the poorer sites as far as frost risk was concerned. Very narrow strips may, however, be more suitable.

(iii) Slope can make a difference if the area is fairly large and regular. Thus, pooling results in distinctly lower temperatures at the corner of Lynford although the slope of 1° was fairly gradual. Probably anything less than 1° does not signify and at West Tofts (½–1°) for example little difference could be discerned in the results between the low west end and the other sites.

(iv) Techniques of assessing years in 10 of frost have produced very similar figures for 1964 and 1965 (although both were untypical years for frost occurrence).

(v) It is doubtful whether climatic change contributes the difficulties of establishing Corsican pine now compared with the 1920's. Winters may have been colder in the last few years than in the 1920's, but frosting in the late spring and early summer is probably a vital factor, and no apparent difference is evident in this respect.

Acknowledgements.—This work has been done in close collaboration with Dr D. H. Phillips and Messrs J. D. Low and B. J. W. Greig (pathologists), and Mr J. M. B. Brown (ecologist) at the Forestry Commission Research Station at Alice Holt, and their co-operation is much appreciated. Very real gratitude is also due to the staff at Thetford Chase for maintaining observations over the three months, mostly to a very high standard of accuracy.

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551.551.5 (262+564.3):629.13

AN INCIDENT OF SEVERE LOW-LEVEL TURBULENCE

By G. J. JEFFERSON

On 14 April 1966, a Canberra aircraft took off from Akrotiri (which lies on the southernmost point of Cyprus) for an exercise flight and climbed away at 3000 feet per minute on a course of 220 degrees over the sea. Turbulence was experienced from take-off but when, at 1730 GMT the aircraft reached a point 25 nautical miles from Akrotiri and an altitude of 8500 feet it experienced some very severe turbulence which turned the aircraft completely over. The pilot managed to regain control, and after completing a half loop, levelled out at 4000 feet and returned to Akrotiri. The aircraft

was fitted with an accelerometer and the crew stated that they observed readings between $+7$ and $-3\ g$.

Investigation of the incident soon revealed that it was by no means an isolated case. Another Canberra returning from El Adem at 1000 feet landed at Akrotiri at 1610 GMT on 14 April after experiencing severe turbulence over the last 80 miles of the flight to Cyprus. Yet another Canberra which took off from Akrotiri on an exercise at 1550 GMT climbed from 10 miles south of Akrotiri on a course of 270 degrees. It experienced very severe turbulence while climbing from 4000 to 16,000 feet, accelerometer readings from $+3$ to $-1\frac{1}{2}\ g$ being observed. Yukon aircraft of the Royal Canadian Air Force reported clear air turbulence over the Nicosia Flight Information Region at 1615 GMT (exact position and height unknown). At 1940 GMT a Comet reported moderate to severe clear air turbulence at 7500 feet, 17 nautical miles north-east of Akrotiri. A Viscount aircraft of Cyprus Airways en route from Tel Aviv to Nicosia flying at 14,000 feet reported light clear air turbulence to 20 miles south of Cyprus. From this point into Nicosia where it landed at 1310 GMT it reported severe clear air turbulence over the mountains.

Some turbulence was still in existence some hours after this as evidenced by a British United Airways Britannia aircraft on a trooping flight from Gatwick to Akrotiri which landed at 0332 GMT on 15 April. A member of the meteorological office staff who was travelling on this aircraft reported that there was light, occasionally moderate, turbulence in medium layer cloud on descent from 24,000 feet and some slight turbulence just before landing. A Comet aircraft of Olympic Airways flying from Beirut which landed at Nicosia at 0740 GMT on 15 April reported severe clear air turbulence above 8000 feet but the exact height, position and duration are unknown.

The turbulence on the 14th and 15th occurred in a fairly densely flown area and a number of other reports are available in addition to the primary one of great severity.

Interesting features which come to light are

(*a*) that although primarily at low levels, turbulence was experienced nearly as high as 24,000 feet, and,

(*b*) the period over which it is known to have extended was from about 1300 GMT 14 April to 0740 GMT 15 April, about $18\frac{1}{2}$ hours.

It seems likely however from the reports that turbulence at the higher levels was associated with unstable medium cloud and that there was also orographic turbulence over Cyprus.

Reports from Cyprus stations show that there was a complete cover of medium cloud throughout the period. The only low cloud was well-broken stratocumulus but much of the time there was nil.

It is clear therefore that the major low-level turbulence was not associated with convection cloud. The winds at the time were not in an off-shore direction in southern Cyprus and in view of the distance of the major incident from the nearest high ground it seems likely that it was not caused by orographic effects.

As with the Derna case described by Grimmer[1] the worst turbulence occurred in clear air about 25 miles from the nearest land but in this case

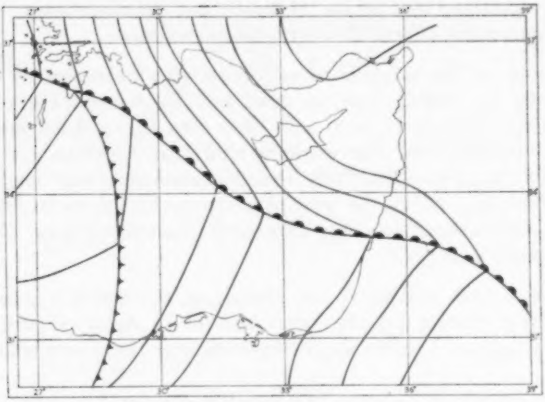

FIGURE 1(*a*)—SYNOPTIC SITUATION 1200 GMT 14 APRIL 1966

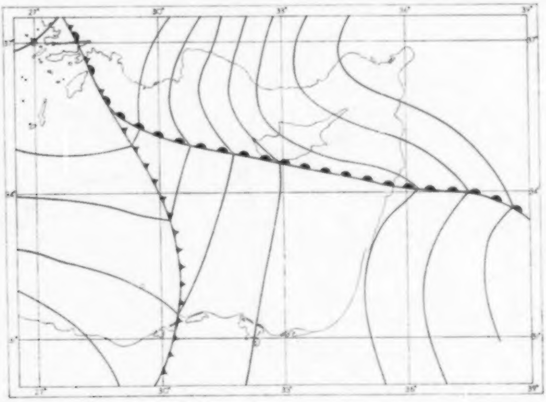

FIGURE 1(*b*)—SYNOPTIC SITUATION 1800 GMT 14 APRIL 1966

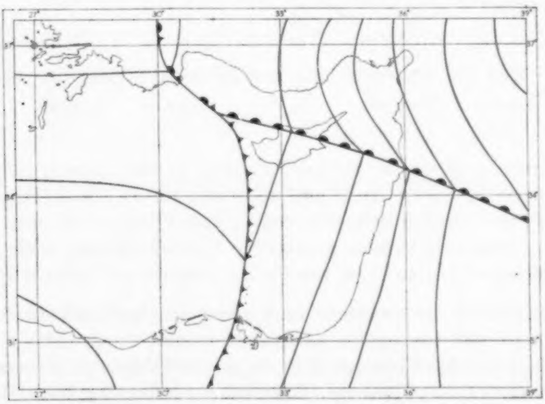

FIGURE 1(*c*)—SYNOPTIC SITUATION 0600 GMT 15 APRIL 1966
Isobar interval 2 mb; pressure at 31°N 30°E rose from 1004 to 1005 mb.

well on the windward side of it. It could not therefore have been caused by the rotor streaming effects of orographic turbulence.

An inspection of the synoptic situation shows similarities to the features associated with the Derna case as described by Kirk[2]. Figures 1(*a*) – (*c*) show the surface analysis at 1200 and 1800 GMT on 14 April and 0000 GMT on 15 April—copied from the working charts at Episkopi. At 1800 GMT, approximately the time that the worst turbulence was encountered, a depression centre lay well to the west over Greece and a warm front is shown lying east to west almost touching the south coast of Cyprus. A cold front lies north to south near 30°E.

The surface frontal analysis is also shown on the 850 mb charts for 1200 GMT on 14 April (Figure 2*a*) and 0000 GMT on 15 April (Figure 2*b*), which clearly show a tongue of warm air corresponding to the warm sector.

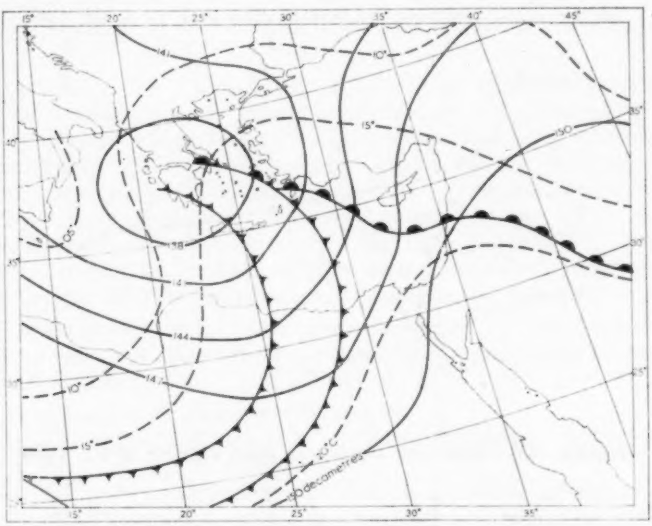

FIGURE 2(*a*)—850 MB CONTOURS AND ISOTHERMS AT 1200 GMT 14 APRIL 1966

——— Contours — — — — Isotherms

The penetration of warm air over Cyprus is well shown by the Nicosia ascents for 1200 GMT on 14 April and 0000 GMT on 15 April (Figure 3) which indicate that the warming was confined to layers below 700 mb. The ascent at 1200 GMT is generally similar to that for Tobruk (Kirk[2]) with an inversion layer between layers whose lapse rates were near the dry adiabatic.

The rise of surface temperature took place in the Episkopi–Akrotiri area about 1700 GMT and was quite noticeable at the time. The rise is shown on the thermograms for Episkopi (Figure 4*a*) and Akrotiri (Figure 4*b*). After a fall in the afternoon at Episkopi there was a sudden rise from 20°C to 23°C in a few minutes followed by a more gradual rise to 25°C.

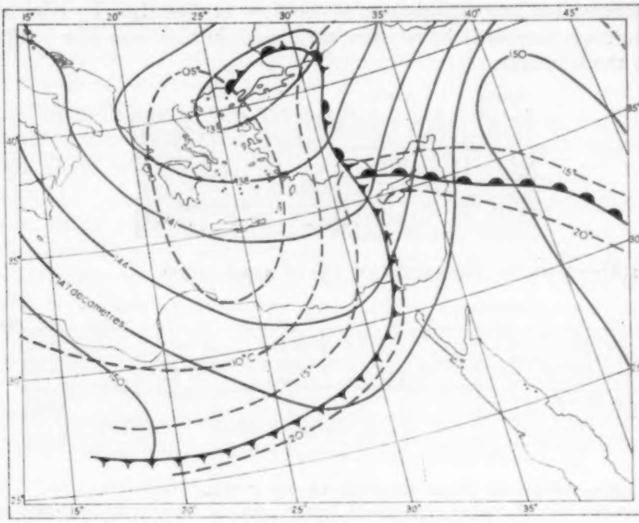

FIGURE 2(*b*)—850 MB CONTOURS AND ISOTHERMS AT AT 0000 GMT 15 APRIL 1966

——————— Contours　　　　— — — — — Isotherms

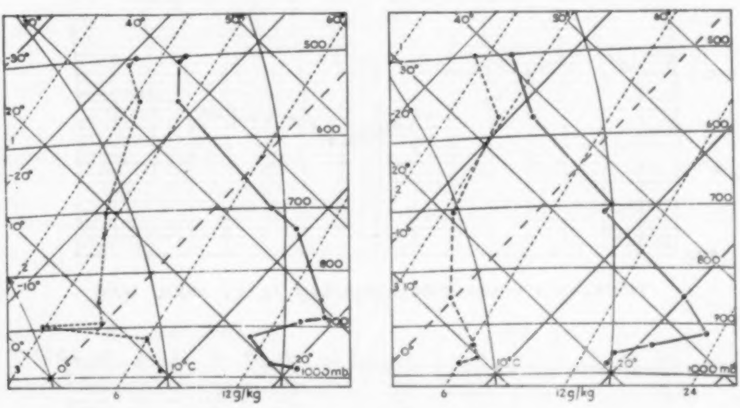

FIGURE 3—NICOSIA RADIOSONDE OBSERVATIONS

(*a*) 1200 GMT 14 APRIL 1966　　　　(*b*) 0000 GMT 15 APRIL 1966

——————— Dry-bulb　　　　— — — — — Dew-point

At the same time the barograms for Akrotiri and Episkopi (Figures 5*a* and 5*b*) both show rapid pressure oscillations between 1630 GMT on 14 April and 0600 GMT on 15 April with a small pressure jump at about 1730 GMT. The possibility therefore exists, especially in view of the limited vertical extent of the warm air, that the warm front drawn on the chart was more

n the nature of a line disturbance of the flow as described by Kirk and that the turbulence may well have been associated in this case also with gravity waves at the interface.

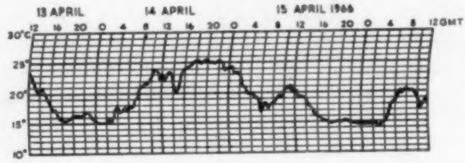

FIGURE 4(*a*)—EPISKOPI THERMOGRAM 13–16 APRIL 1966

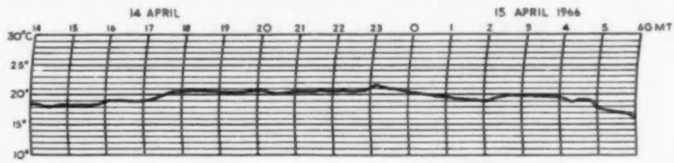

FIGURE 4(*b*)—AKROTIRI THERMOGRAM 14–15 APRIL 1966
The temperature record reads low ; screen temperature at 1800, 0000 and 0600 GMT were 21·3, 20·8 and 17·5°C.

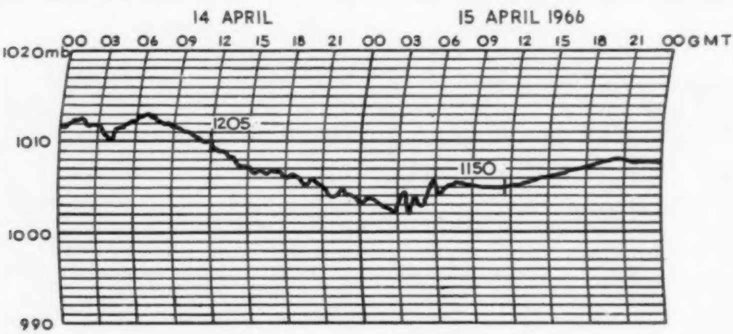

FIGURE 5(*a*)—AKROTIRI BAROGRAM 14–15 APRIL 1966

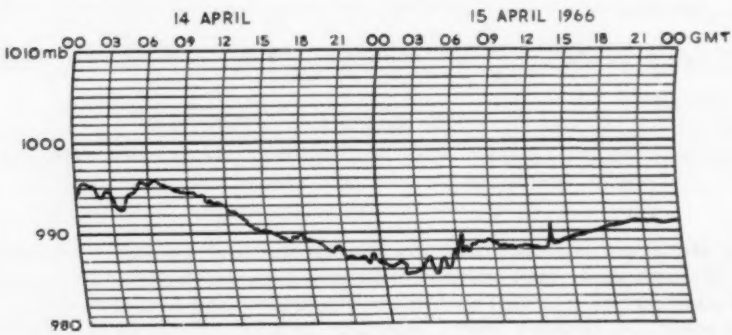

FIGURE 5(*b*)—EPISKOPI BAROGRAM 14–15 APRIL 1966

The 850 mb charts (Figures 2*a* and 2*b*) bear a strong resemblance to those of the Derna case (Kirk[2] Figures 9 and 10) with a sharp warm ridge, but with the difference that on 14 April the turbulence occurred in a position where warm air advection was occurring.

Another feature similar to the Derna case is that the winds for 1800 GMT on 14 April at Cyprus stations given in Table I show a very marked veer with height in the lower levels.

Although no attempt is made at a more detailed explanation of the mechanism which could produce turbulence of the severity observed well away from land in what would previously have been regarded as unlikely conditions of clear air at low levels, certain common factors are noted which may enable some attempt to be made to forecast such occurrences on future occasions. They are

(*a*) a surface warm or cold 'front' with oscillating pressure including pressure jumps,

(*b*) a sharp thermal ridge at 850 mb,

(*c*) rapid veer of wind with height in the lower layer and

(*d*) tephigram showing an inversion or stable layer between layers whose lapse rates are near the dry adiabatic.

TABLE I—UPPER WINDS IN CYPRUS 1800 GMT 14 APRIL 1966

Height in feet	Ayios Nicolaos	Nicosia	Paphos
		degrees/knots	
1000	060/29	—	120/26
3000	160/23	140/26	190/34
5000	225/20	210/29	230/36
7000	240/30	220/35	
10000		220/37	

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REVIEWS

Investigation of the bottom 300-meter layer of the atmosphere edited by N. L. Byzova. 9¾ in × 7 in, pp. v + 112, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London, EC1, 1965. Price : 27*s*.

This set of papers published by the Academy of Sciences of the U.S.S.R. and now appearing in translated form provides an interesting reflection of the Russian position in the study of atmospheric diffusion and transport processes. All the papers involve measurements made on a 300-m mast, the geographical location and other details of which are, however, completely omitted. Seven deal with instruments and measuring techniques, three discuss the wind and temperature profiles and turbulence data so obtained, two are concerned with experiments on the spread of material from a point source and one with the statistical representation of turbulence measurements.

Not surprisingly the main fundamental background is provided by the well-known Russian developments in similarity theory of profiles and inertial sub-range theory of turbulence, but the collection is not without reference to Western contributions. In the context of diffusion from a continuous point source research workers here may be surprised at the emphasis given to inertial sub-range considerations and also at the adherence to a K-theory for cross-wind spread. On the whole, however, the collection makes stimulating and informative reading for anyone with a special interest in this particular field.

F. PASQUILL

Objective analysis of meteorological fields, by L. S. Gandin. $9\frac{3}{4}$ in $\times$ 7 in, pp. vi +242, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London, EC1, 1965. Price : 81*s*.

The requirement for real-time production of numerical forecasts as a routine has stimulated investigation of two allied problems—automatic processing of coded data, and methods of objective analysis of surface and upper air charts. They are now however assuming major importance in their own right ; their successful solution could eliminate many of the meteorologist's more laborious tasks. With the former considerable success has been achieved ; data extraction by computer is already fully as efficient as the human variety. In the field of analysis, subjective methods still have a long lead, but much progress has been made.

Though this book discusses the whole field of objective analysis, it is primarily concerned with upper air contour charts. The various objective methods have a common approach in that they attempt to estimate contour heights at a network of points independently – a fundamentally different approach from the human analyst's. In his initial chapter, the author reviews methods developed outside the U.S.S.R. Basically these are two in number. One starts with an initial guess field normally derived from an earlier forecast, and successively modifies it in the light of observations. This method is in operational use in the U.S.A. and elsewhere. The other consists in fitting the best surface in the vicinity of each grid point to accommodate both observations and forecast field, suitable relative weighting factors being allotted. This is in current use in the Meteorological Office, additional corrections having been introduced to correct particular defects. The author comments reasonably enough that the arbitrariness of these approaches hardly justifies the term 'objective'.

The main part of the book describes a third approach developed in the Soviet Union at the Main Geophysical Observatory. This makes use of the statistical correlation of meteorological elements with distance. In the case of a contour chart, the differences of observed heights from their seasonal means are used to form estimated values using computed correlation functions. Winds, converted to geostrophic gradients, are handled similarly. The treatment is mathematically logical, and avoids the empiricism of such parameters as distance weighting functions employed by other systems. The method may be extended to other elements, and examples are shown of correlation functions for 500 mb height, surface pressure, and 850 mb dew-point.

Comparisons given by Gandin of the different analysis techniques appear to favour the Russian system.

However one must confess to some doubts. The conditions of the comparison hardly do justice to the alternative methods, and the statistical verification itself is too clearly allied to the proposed analysis technique. In the examples of charts derived objectively by the correlation method, the analyses are excellent over land areas, but the quality over the Atlantic appears poor. One can also visualize the risk of an occasional 'howler', such as a small high in the centre of a depression. However, the technique is clearly capable of further development. So far no meteorological service has been able to rely on routine objective analyses without human monitoring.

The final chapters deal with other practical aspects of the production of computed analyses, from data processing to methods of chart output, but in this fast-developing subject, the ideas have been overtaken by events. The book itself is well produced and includes a comprehensive bibliography. Published in Israel as one of a series of scientific translations, it leaves nothing to be desired in clarity of expression and completeness of editing.

P. GRAYSTONE

Weather Studies, by L. P. Smith. $7\frac{3}{4}$ in × $5\frac{1}{4}$ in, pp. vii + 131, *illus.*, Pergamon Press, Headington Hill Hall, Oxford, 1966. Price : 15*s*.

This book, which is part of a series on Rural Studies, is written in a clear, straightforward style and should be easily understood by the average person. It is divided into a large number of topics, for each of which there is an explanation followed by an 'assignment'. The latter consists of experimental work to enable the reader to discover facts for himself, and thus gain a better understanding of the subject.

The book contains five parts, covering weather observations and measurements, the plotting of the measurements on graphs, the relationship between the various aspects of weather, local weather, and finally some hints on weather forecasting based on the reader's own observations. The work is well illustrated by graphs, diagrams, maps and a number of photographs of common cloud types.

'Weather Studies' should prove useful to teachers, especially those in charge of school weather stations. It is suitable for pupils of all ages in Secondary schools and in the final year in Junior schools. It could form part of a general science course particularly in schools in rural and coastal areas. It could also be used as a supplementary book by students of physics and geography and should have a place in the school library for the use of individual pupils.

This is a stimulating book which should appeal to anyone who is interested in the weather, and should encourage many who are considering setting up their own weather stations. Perhaps a small section on the siting and equipping of such a station at a minimum of cost would have been a useful addition to the book. The author's preference for the Fahrenheit scale of temperature seems a little out of place in a book which will be used in schools where teachers are trying to persuade their pupils to think in terms of the centigrade scale.

F. R. DOBSON

LETTER TO THE EDITOR

551.515.3

Waterspout seen off Shetland on 22 November 1965

Weather conditions off Shetland on 22 November 1965 and details of a waterspout observed (Plate I) are given in the following account by Captain J. A. MacDonald of BEA.

'The aircraft landed at Sumburgh Airport at 1410 GMT in a heavy snow shower which had lasted for over an hour. The wind was north-north-westerly, about 10 knots, temperature was just above freezing, and the snow was coming from a large cumulus or cumulonimbus cloud which gave complete cloud cover in the vicinity. Shortly after the landing, the shower passed and the sky cleared, with a drop in temperature to below freezing. Such were the conditions when the aircraft took off again at 1535 GMT.

Immediately after take-off, a left turn was initiated on to a south-west heading. Although the sky was clear immediately overhead, the aircraft was heading towards a bank of smallish cumulus or fracto-cumulus cloud with an estimated base of 800–900 feet above sea level. Visibility was good and the temperature was steady at around −1°C from take-off to 600 feet (not noted above this height). The cloud looked perfectly normal and innocuous, except for the cone of cloud which, following a crooked path, stretched from the base of the cloud to the surface of the sea (see Plate I). In appearance, it was curved and dense with an average diameter estimated at 30 feet, though at the top the diameter was slightly larger. Where it touched the surface of the sea, the sea was turbulent and appeared to be luminescent. There was no precipitation in the immediate area, which was approximately 10 miles south-west of Sumburgh Head.

During the climb into a neighbouring bank of similar-looking cloud some 2 miles from the waterspout, slight turbulence was experienced.'

On 22 November a northerly airstream brought an unstable polar air mass over the Shetland Isles. The 1000–500 mb thickness of 5120 geopotential metres (gpm) at 1130 GMT at Lerwick was unusually low—the minimum over the five-year period 1950–54 was 5160 gpm. The unstable air gave rather frequent showers of snow and hail some of which were heavy and prolonged. Surface temperatures reported by Lerwick Observatory were at or below freezing-point though sea surface temperatures were around 9°C. The frequency of waterspouts* in the northern hemisphere reaches its maximum in October-November but occurrences are relatively rare in the latitude of Lerwick.

R. WILSON

* GORDON, A. H.; Waterspouts, *Mar. Obsr, London*, **21**, Part I p. 47 and Part II p. 87.

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CONTENTS

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